Response to Parisi's Comment on "Non-mean-field behavior of realistic spin glasses"

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We expand on why our recent results rule out the standard SK picture of realistic spin glasses.

In his Comment [1] on our paper [2], Parisi argues that our two constructions of P_J are self-averaging only because neither is the "correct" one, which is an infinite volume object (i.e., L has already been taken to ∞) that *does* depend on J (in the spin glass phase).

We discuss below Parisi's analysis of our constructions. But first, we make a more important point, concerning the conventional formulation (as in [1]) of the mean field predictions for realistic models (called the "standard SK picture" in [3]): a central conclusion of [2] is that there cannot exist *any* P_J which is both an infinite volume object *and* which depends on J — at least not unless it has the physically peculiar property of depending on the choice of the origin of the coordinate system. This is an immediate (and rigorous) consequence of the spatial ergodicity of the underlying disorder distribution, as explained in [2]: any translation invariant (infinite volume) P_J must be self-averaging. The standard SK picture is therefore self-contradicting.

What about the claims in [1] about our two constructions? We first note that the two constructions of [1] are not the same as ours, because the latter implicitly take an overlap $q_{R'}$ with $R' \neq R$, the box size where the couplings are fixed. For example, for the second P_J of [2], which we denote by P_J^{II}, $R' \ll R$. These differences are subtle, but can lead to quite different P_J's due to finite size effects, as emphasized in [4]. We will not dwell on these issues here, but will address Parisi's claim that our second $P_J(q)$ is independent of J because it is a delta-function.

1. Must $P_J^{II}(q) = \delta(q)$ due to the "chaotic nature of spin glasses", as asserted in [1]? No; the "nonstandard" SK picture of [3] has just such a chaotic nature, but there $P_J^{II}(q)$ could be continuous and nonzero everywhere between $\pm q_{EA}$ (with no delta-functions at those points).

2. Could $P_J^{II}(q) = \delta(q)$ when there are many pure states? Yes; as already noted in [2], this occurs in the model of Ref. [5]. For realistic models, it could occur in the context of possibility 5 in Ref. [3] and would mean that the overlaps between pure states are not a good choice of order parameter.

In [1], Parisi defines his $P_J(q)$ first for finite L and then takes $L \to \infty$. But if there are many pure states, then this limit should not exist because of chaotic size dependence [6]. We have not found in the literature any construction (other than ours or related ones [7]) of a natural infinite-volume $P_J(q)$ for short-ranged spin glasses.

We would welcome such a construction, but we emphasize that any infinite-volume $P_J(q)$ which has the very weak and natural property of translation-invariance will be automatically self-averaging.

Does all this prove that mean-field theory is irrelevant to realistic spin glasses? Not yet. In [3], we present an approach to realistic disordered (and other) systems, which *might* allow some mean-field features to persist. A key aspect of this approach is that in infinite volume, dependence on J is replaced by a more subtle type of dependence. As discussed in [3], this type of dependence is fully consistent both with the observation of Guerra [8] that taking replicas and infinite volume limits in different orders could lead to different results, and with the possibility of replica symmetry breaking. However, the resulting nonstandard SK picture differs considerably from the standard one; in particular, there is no dependence of (infinite volume) overlap distributions on J and there cannot be ultrametricity of overlaps among *all* pure states. We refer the reader to [3] for further details.

[1] G. Parisi, "Recent rigorous results support the predictions of spontaneously broken replica symmetry for realistic spin glasses", preprint, March, 1996. Available as cond-mat preprint 9603101 at http://www.sissa.it/.

[2] C.M. Newman and D.L. Stein, *Phys. Rev. Lett.* **76**, 515 (1996).

[3] C.M. Newman and D.L. Stein, "Spatial inhomogeneity and thermodynamic chaos", October 1995. Available at http://www.physics.arizona.edu~dls, or as adap-org preprint # 9511001.

[4] D.A. Huse and D.S. Fisher, *J. Phys. A* **20**, L997 (1987).

[5] C.M. Newman and D.L. Stein, *Phys. Rev. Lett.* **72**, 2286 (1994).

[6] C.M. Newman and D.L. Stein, *Phys. Rev. B* **46**, 973 (1992).

[7] M. Aizenman and J. Wehr, *Comm. Math. Phys.* **130**, 489 (1990); A. Gandolfi, M. Keane, and C.M. Newman, *Prob. Theory Rel. Fields* **92**, 511 (1992).

[8] F. Guerra, private communication; see also "About the overlap distribution in mean field spin glass models", preprint, November, 1995.